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$\bar{p}p$ ANNIHILATION INTO NEUTRAL KAONS

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Presented by C. Amsler

Abstract

We have observed $\bar{p}p$ annihilation at rest into K_SK_S using a hydrogen gas target at normal temperature and pressure. This channel is forbidden from atomic $\bar{p}p$ S states. A preliminary analysis gives a branching ratio of $(2.2 \pm 0.5 \pm 0.5) \times 10^{-5}$. We have also observed the channel K_SX where X is a K_S or K_L escaping detection in our apparatus. The K_SK_L mode is allowed from atomic S but forbidden from atomic P orbitals. Using the known branching ratio of $(7.8 \pm 0.4) \times 10^{-4}$ for $\bar{p}p \to K_SK_L$ and our preliminary figure of $(3.8 \pm 0.4 \pm 0.8) \times 10^{-4}$ for K_SX we deduce that the fraction of S state annihilation in hydrogen gas at NTP is (46 ± 10) %. This in turn yields an absolute branching ratio of $(4.1 \pm 0.9 \pm 1.0) \times 10^{-5}$ for $\bar{p}p \to K_SK_S$ from P orbitals, showing that the $(K_SK_S+K_LK_L)$ mode is suppressed by an order of magnitude compared to the K_SK_L mode.

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Introduction

Antiproton-proton annihilation at rest into $K_S K_S$ has not been observed in liquid hydrogen. Only four candidate events have been reported [1]. On the other hand annihilation at rest into $K_S K_L$ occurs at a rate of $(0.78 \pm 0.04) \times 10^{-3}$ in liquid hydrogen [2]. Parity and charge conjugation conservations forbid the $K_S K_S + K_L K_L$ mode from $\bar{p}p$ atomic S states, but allows the $K_S K_L$ mode from the $^3S_1$ state. The situation is reversed for $\bar{p}p$ annihilation from atomic P states: $K_S K_S + K_L K_L$ is allowed from the $^3P_2$ and $^3P_0$ orbitals while $K_S K_L$ is strictly forbidden.

The non-observation of $K_S K_S$ was used to derive a 95 % confidence level upper limit of 6 % for P wave annihilation in liquid hydrogen [3]. The high collision rate in liquid, inducing Stark mixing (Day-Snow-Sucher mechanism [4]), populates the high S orbitals of the antiprotonic atom from which the $\bar{p}p$ system annihilates (large overlap of the wave functions due to the absence of angular momentum barrier). In gaseous hydrogen, on the other hand, the reduced collision rate enables a substantial fraction of annihilation from atomic P levels. Our recent data [5] show indeed that a large fraction of $\bar{p}p$ annihilation in gaseous hydrogen at normal temperature and pressure proceeds through P state annihilation. We have searched for the channels $K_S K_S$ and $K_S K_L$ in gaseous hydrogen to establish the relative contribution of S and P wave in gas and the absolute branching ratio for $\bar{p}p \to K_S K_S$ for P wave annihilation.

$\bar{p}p \to K_S K_S$

Antiprotons from LEAR enter a solenoidal magnetic detector (0.8T). After passing through a moderator they stop in a 76 cm long, 16 cm diameter hydrogen target (NTP). Stopping $\bar{p}$ are defined by a scintillation counter telescope followed by a veto counter. Typically 10^4 $\bar{p}$/s enter the telescope. An argon/ethane drift chamber surrounds the hydrogen target. The momenta of the outgoing particles are measured by the drift chamber and seven cylindrical multiwire proportional chambers with anode (ϕ) and cathode (z) readout. The solid angle acceptance is 2π. The vertex from which a pair of tracks emerge is determined by computing the distance of closest approach. A more detailed description of the apparatus can be found elsewhere [6].

A total of 1.5×10^6 annihilations into 4 prongs were examined. Events were required to have two pairs of tracks each consistent with the invariant mass condition

$$445 < m(\pi^+\pi^-) < 545 \text{ MeV}$$

assuming pions in the final state. The total measured momentum was required to be less than 200 MeV/c. The events were then submitted to a 4C kinematics fit to $\bar{p}p \to 2\pi^+ 2\pi^-$. The 2π invariant mass of the fitted 1730 events is shown in fig.1a. The corresponding scatterplot $m(\pi^+_1\pi^-_2)$ versus $m(\pi^+_3\pi^-_4)$ is shown in fig.1b. No obvious enhancement is observed at the K^0 mass (497 MeV). Fig.1c shows the distribution of the distance between the two vertices. For $\bar{p}p \to K_S K_S$ this distance d is expected to follow the probability distribution

$$f(d) = (d/\Lambda^2)\exp(-d/\Lambda)$$

where Λ is the K_S mean free path (4.3 cm). The average distance is 2Λ. Fig.2 shows the 2π invariant mass distribution for events with a vertex separation of at least 3 cm. A clear $K_S K_S$ signal of 22 events is observed in the mass range 488 to 508 MeV. The background contribution is estimated from side bins to be less than 2 events. The mass resolution is 8 MeV.

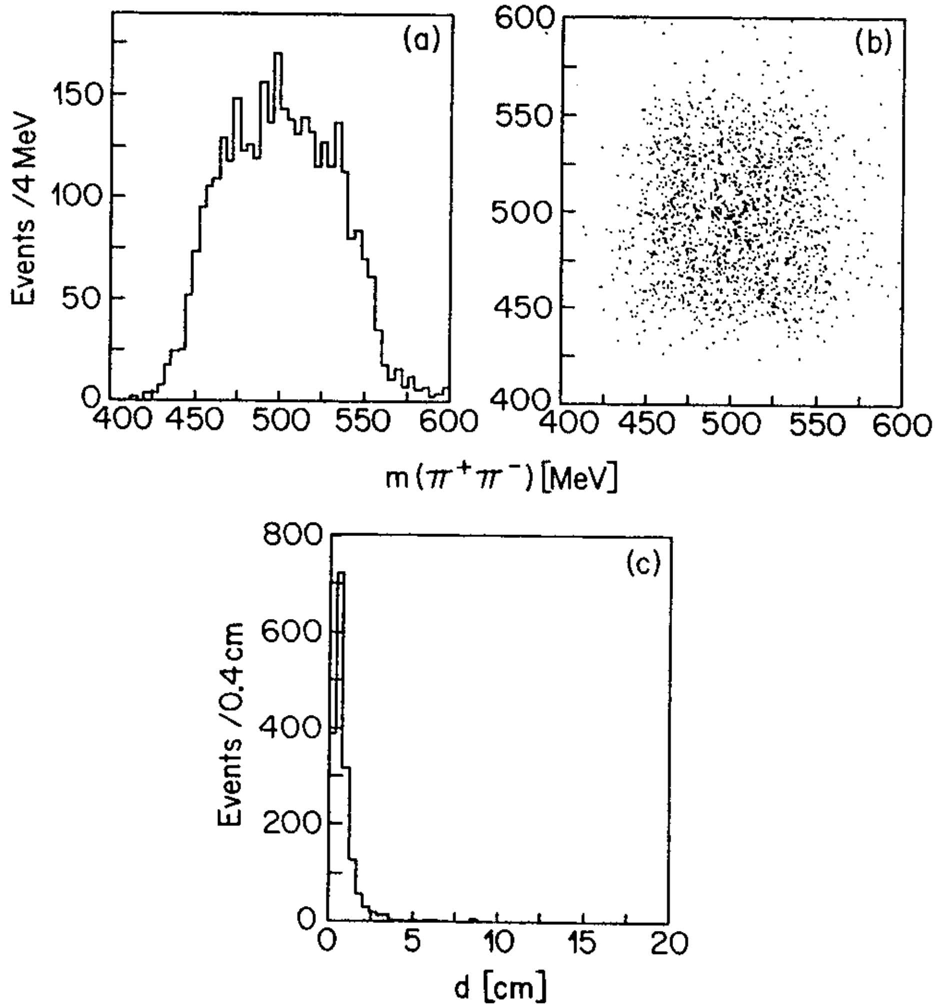

Figure 1a: 2π invariant mass (2 combinations per event).
b: $m(\pi^+_1\pi^-_2)$ versus $m(\pi^+_3\pi^-_4)$.
c: Distribution of vertex separation.

The angular distribution of the π^+ in the K_S rest frame, shown in fig. 3, is consistent with isotropy ($\chi^2 = 7.5$ for 9 degrees of freedom). A maximum likelihood fit to the vertex separation ($d > 3$ cm) yields a mean K_S lifetime of $(0.85 \pm 0.12) \times 10^{-10}$ s in agreement with the table value $(0.892 \pm 0.002) \times 10^{-10}$ s.

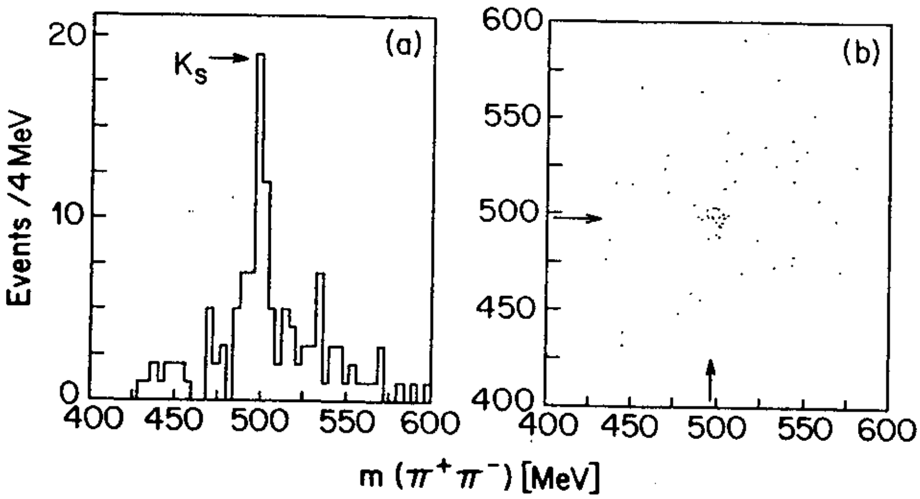

Figure 2a: 2π invariant mass for events with vertices separated by more than 3 cm.
b: $m(\pi^+{}_1\pi^-{}_2)$ versus $m(\pi^+{}_3\pi^-{}_4)$.

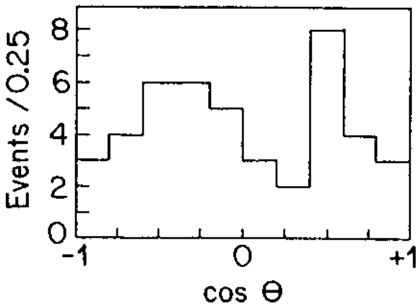

Figure 3: cosΘ distribution of the π^+ in the c.m.s. frame of the $\pi^+\pi^-$ pair.

We conclude therefore that we have observed the annihilation channel $\bar{p}p \rightarrow K_S K_S$. Fig. 4 shows a typical $K_S K_S$ event in the ASTERIX detector.

The branching ratio was calculated by Monte Carlo simulation of the detector acceptance and the $\bar{p}$ stop distribution in the target. We assumed that the branching ratio for annihilation into four prongs + missing mass is 48 %, in accordance with bubble chamber experiments [2]. Our data show indeed that the charged multiplicity distribution is not significantly different in gaseous hydrogen. Correcting for the unseen $K_S \rightarrow \pi^0\pi^0$ decay mode $(K_S \rightarrow \pi^0\pi^0 / K_S \rightarrow \pi^+\pi^- = 1/2)$, we arrive at a branching ratio of $(2.2 \pm 0.5) \times 10^{-5}$. The systematical normalization uncertainty is estimated to be 25 %.

$\underline{\bar{p}p \rightarrow K_S K_L}$

Since K_L escape detection in our apparatus, we have searched for this channel in $\bar{p}p \rightarrow \pi^+\pi^-$ + missing mass (MM). Fig. 5 shows the missing mass recoiling against $\pi^+\pi^-$ from a sample of 1.6×10^5 annihilations into two prongs.

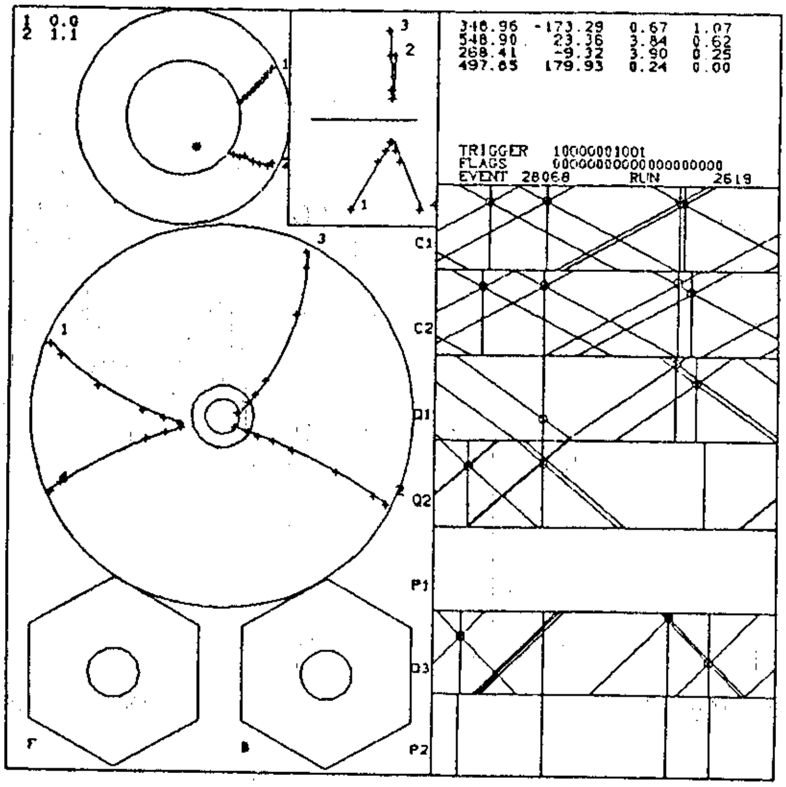

Figure 4: A typical $K_S K_S$ event in the ASTERIX detector. The pattern on the right shows the MWPC wire hits.

For optimum resolution both pions were required to reach the outermost wire chamber. Signals from $\pi^+\pi^-\pi^0$, $\pi^+\pi^-\eta$ and $\pi^+\pi^-\rho^0$ (or ω) are clearly visible above the background from $\bar{p}p \to \pi^+\pi^-MM$ with more than one neutral pion. Events with a detected $K_S \to \pi^+\pi^-$ and a missing K^0 have been looked for within the missing mass window $0.125 < MM^2 < 0.375$ GeV². The upper boundary coincides with the $K_S K^0 \pi^0$ threshold. In addition the total $\pi^+\pi^-$ momentum was required to be more than 650 MeV/c. Fig. 6 shows the corresponding $\pi^+\pi^-$ invariant mass. A clear signal of 80 events appears at the K^0 mass. The events in the peak correspond to $\bar{p}p \to K_S X$ where X is a K_S or a K_L that has escaped detection.

The branching ratio for $K_S X$ was again estimated by Monte Carlo simulation assuming a branching ratio of 42 % [2] for $\bar{p}p$ annnihilation into two prongs and correcting for the unseen $\bar{p}p \to K_S X$ ($K_S \to \pi^0\pi^0$). We find $(3.8 \pm 0.4) \times 10^{-4}$ with a systematical normalization uncertainty of 20 %.

P / S Ratio

The fraction R of S wave annihilation in gas can now be derived:

$$R = [\Gamma_1(K_S X) - \Gamma_1(K_S K_S)]/\Gamma_2(K_S K_L)$$

where $\Gamma_1(K_S X) = 3.8 \times 10^{-4}$, $\Gamma_1(K_S K_S) = 2.2 \times 10^{-5}$ and Γ_2 is the $K_S K_L$ branching ratio in liquid hydrogen (7.8×10^{-4}). We assume that annihilation in liquid is dominantly (≈ 100 %) S state. The relative contribution of annihilation from S orbitals in gaseous hydrogen (NTP) is therefore R = (46 ± 10) %.

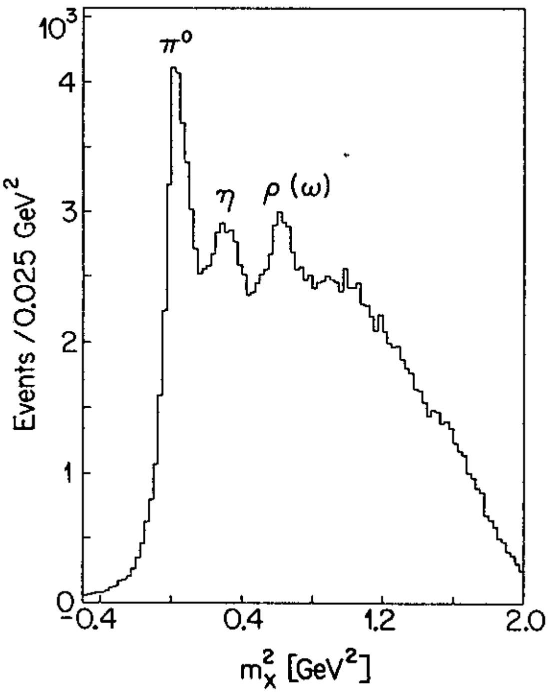

Figure 5: Missing mass² recoiling against $\pi^+\pi^-$.

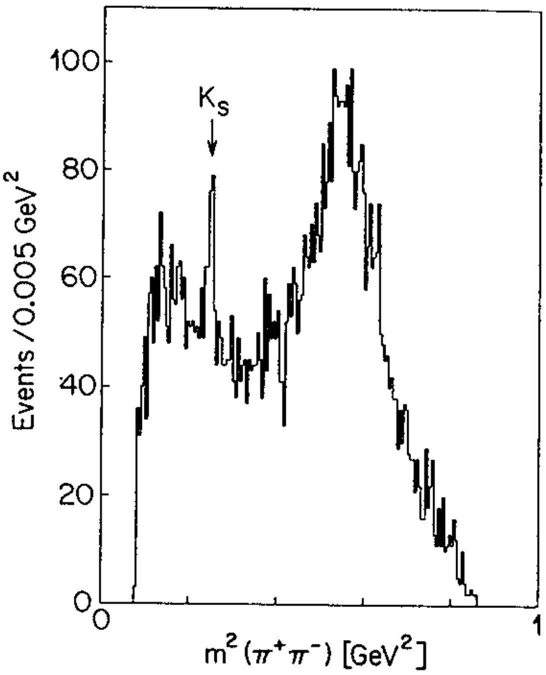

Figure 6 : Invariant $m^2(\pi^+\pi^-)$ for events with a missing mass² in the range 0.125 to 0.375 GeV²and a total $\pi^+\pi^-$ momentum larger than 650 MeV/c.

Our earlier data showed significantly less S wave annihilation in gas [5]. We wish to emphasize at this point that - as explained in [5] - these data were taken with an on-line trigger on X-ray transitions to the 2p state of protonium (L X-rays) thus enhancing P state annihilation.

The absolute branching ratio for $pp \rightarrow K_S K_S$ for $\bar{p}p$ annihilation from atomic P states can now be derived. Since this channel is forbidden from S orbitals, we find a preliminary branching ratio of $(4.1 \pm 0.9) \times 10^{-5}$ with a 25 % normalization uncertainty. Under the assumption of equal contributions from $K_S K_S$ and $K_L K_L$, this result shows that the C = + 1 ($K_S K_S + K_L K_L$) mode is supressed by an order of magnitude compared to the C = -1 $K_S K_L$ mode.

References

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